

# **Experimental study of the out-of-band emission from laser produced Sn plasma**

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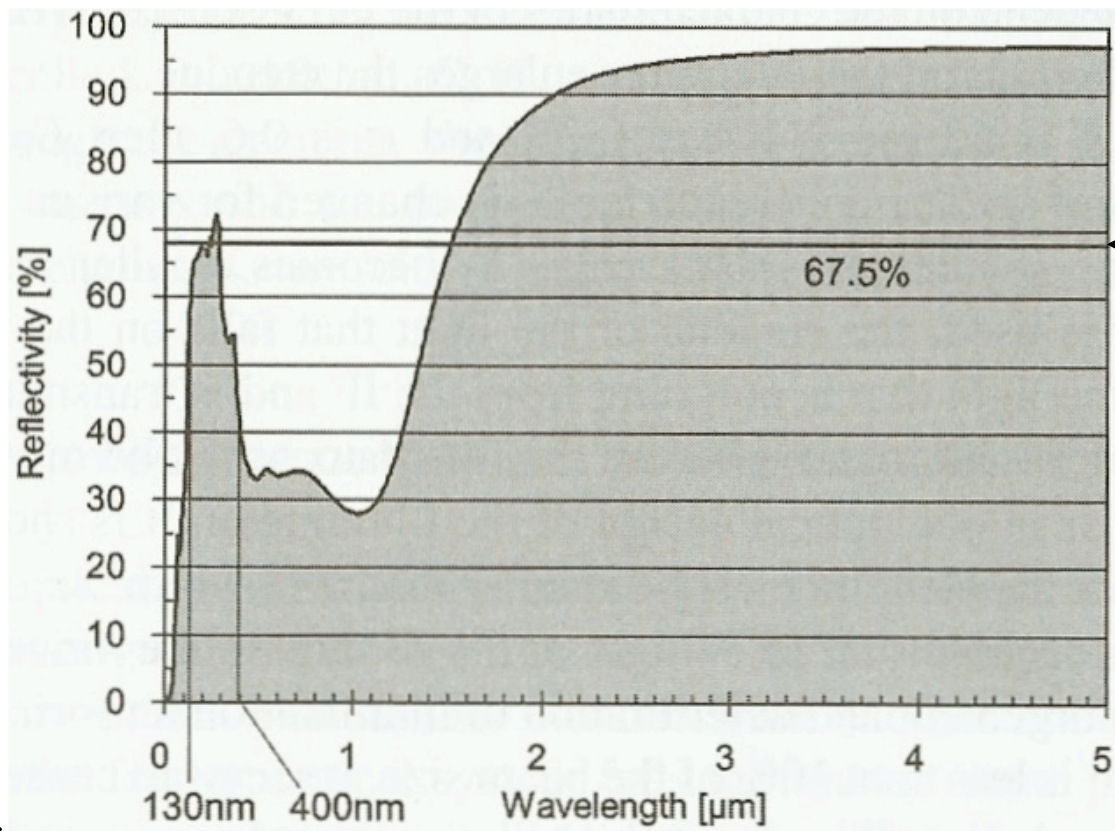
*This work is performed under the auspices of Leading Project promoted by MEXT  
(Japanese Ministry of Education, Culture, Sports, Science and Technology).*

It is highly requested to clarify physics of OoB emission and provide experimental databases on it.

**Joint requirement (*EUV source WS/2006.5*)**

**130 - 400 nm: < 3 - 7 % (< 1% on wafer)**

**> 400 nm: < 0.3 - 3% (< 10 ~ 100% on wafer)**

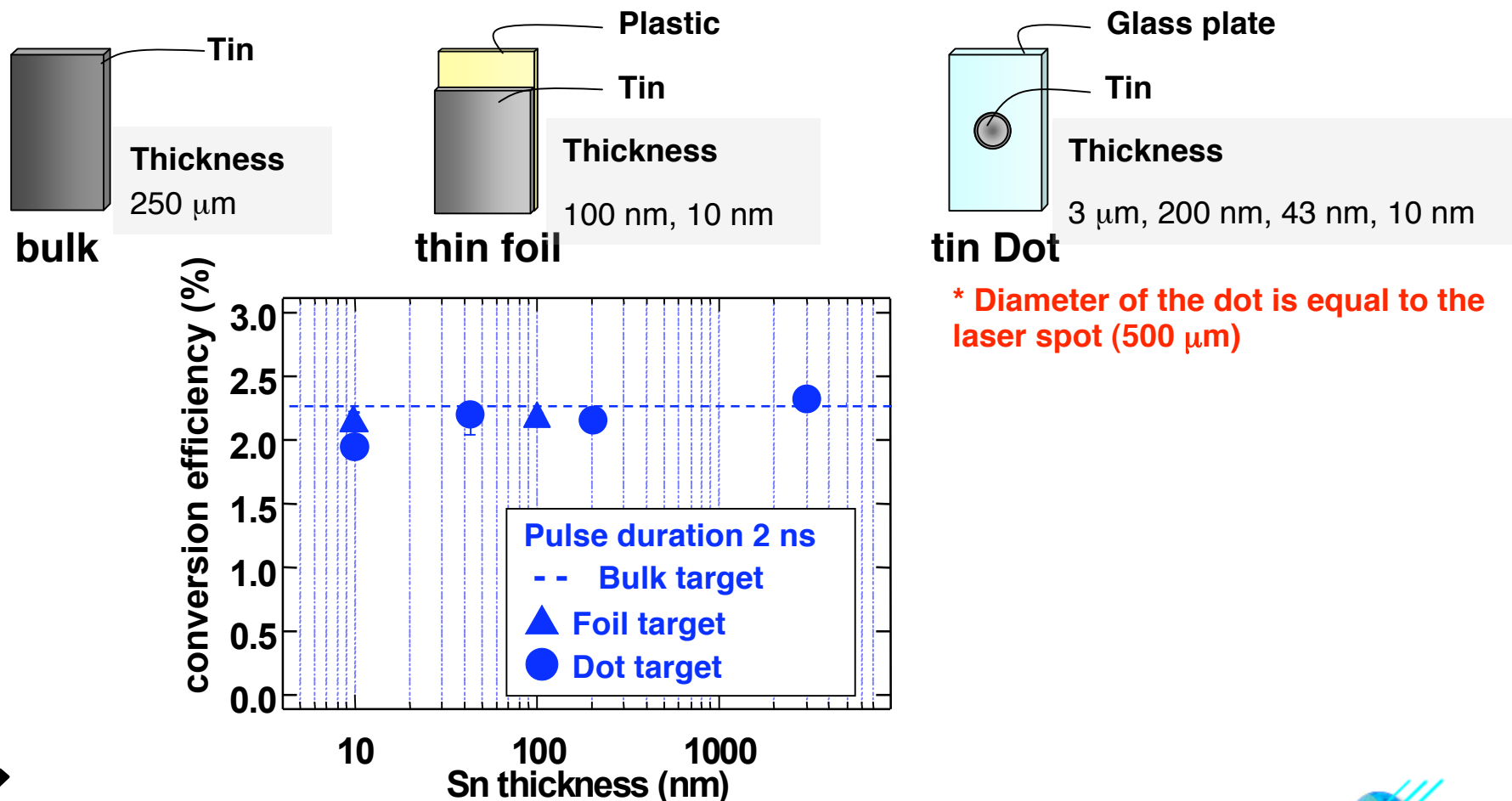


reflectivity at  
13.5 nm

*Reflection and scattering of drive laser above 1 μm-wavelength must be also taken care of.*

The minimum numbers of Sn atoms necessary for EUV pulse generation is  $10^{14} \sim 10^{15}$ . In other words, remaining mass can be a source of OoB emission.

EUV conversion efficiencies show no geometrical dependence for a give Sn mass.

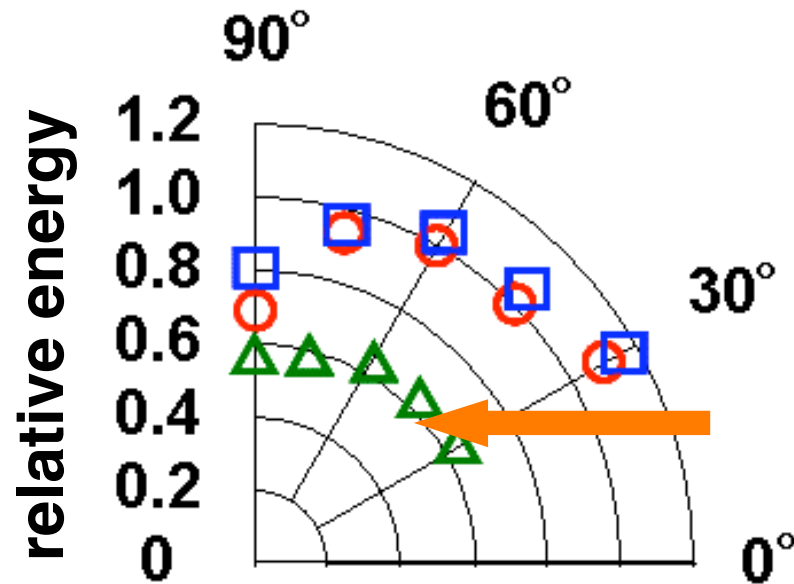


Angular distribution of OoB emission is rather isotropic.  
This result was used to derive absolute OoB energy.

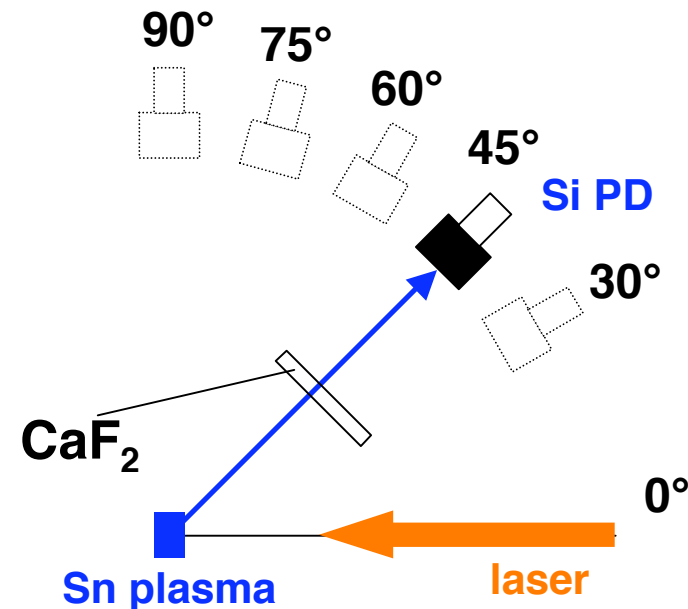
angular distribution

@130–550 nm, 8 ns pulse

- 1-mm-thick bulk Sn
- 1- $\mu$ m-thick Sn-coated plate
- △ 1- $\mu$ m-thick Sn-coated sphere

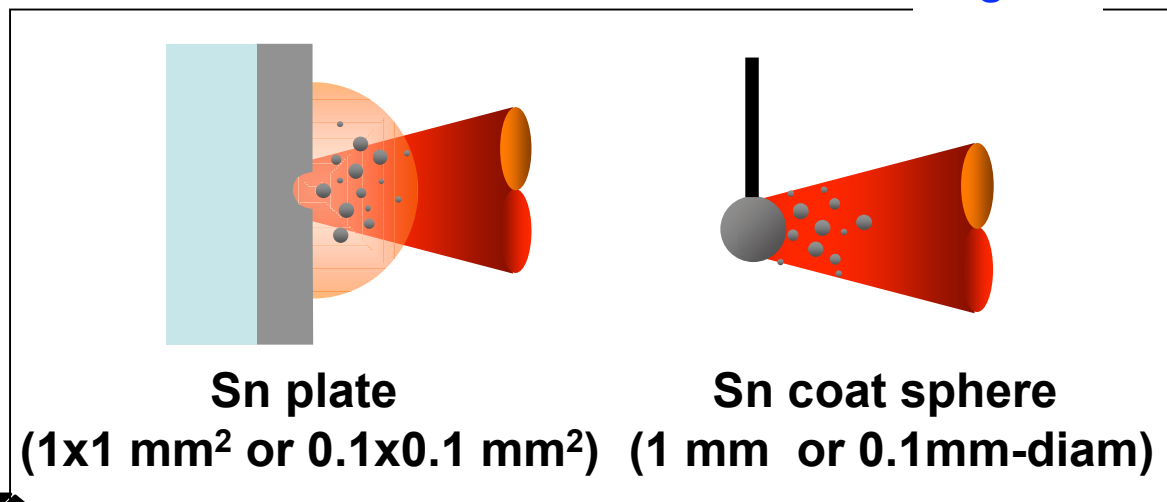
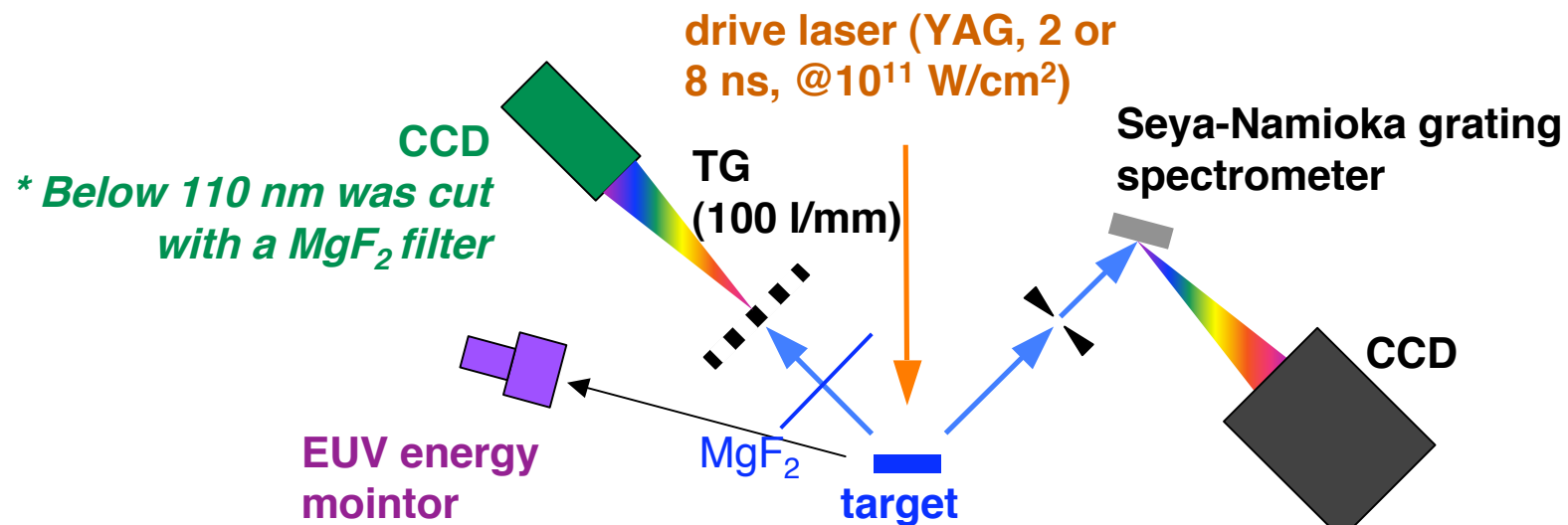


top-view



Sn target:  
1-mm-thick plate  
1- $\mu$ m-thick plate  
1- $\mu$ m-thick coat sphere

# Dependence of OoB emission on target structures and sizes were investigated to identify the source region

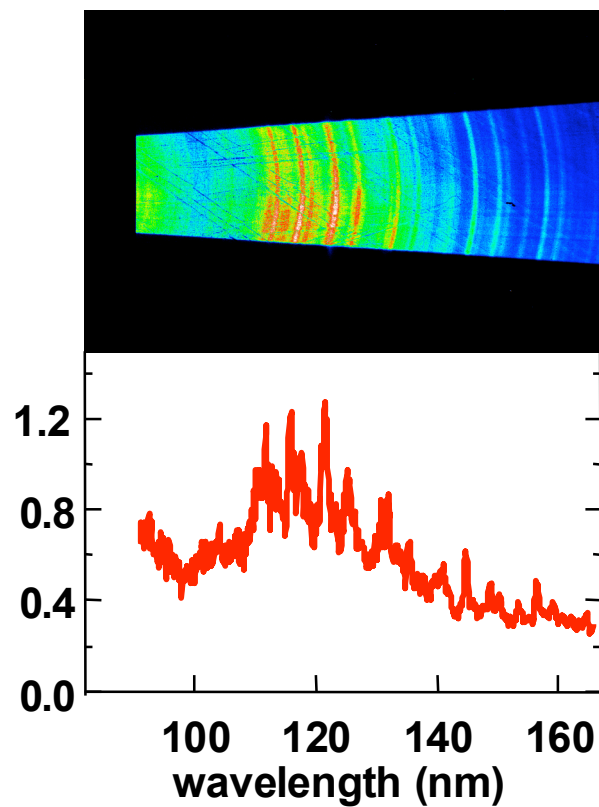


Absolute measurement of OoB was done with TG-CCD (using nominal values), and fine structures of OoB spectrum were observed with SN spectrograph.

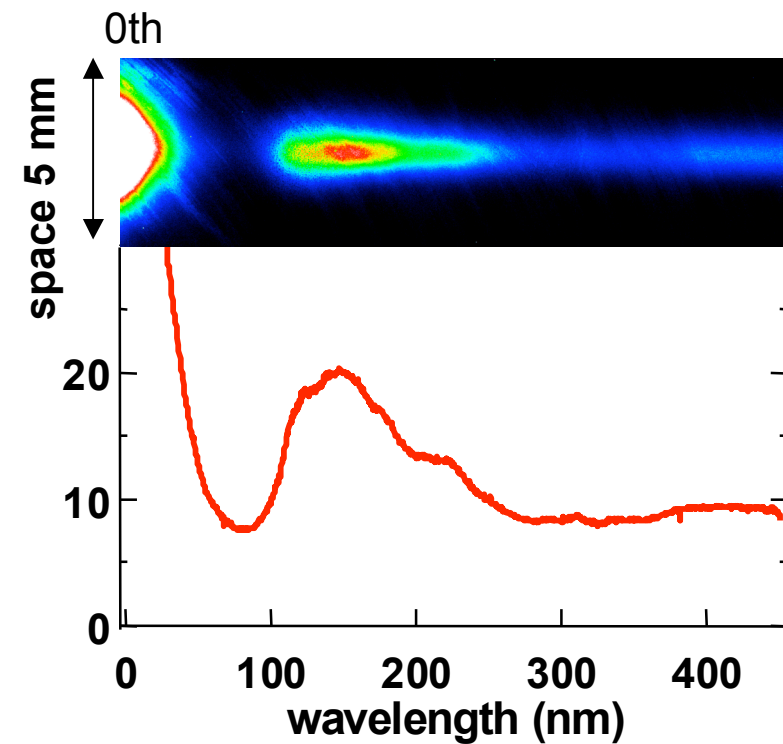
Separately, absolute calibration was done using SOR. Data analyses are in progress.

# Typical spectra from SN spectrograph and TG-CCD

from SN spectrograph



from TG-CCD



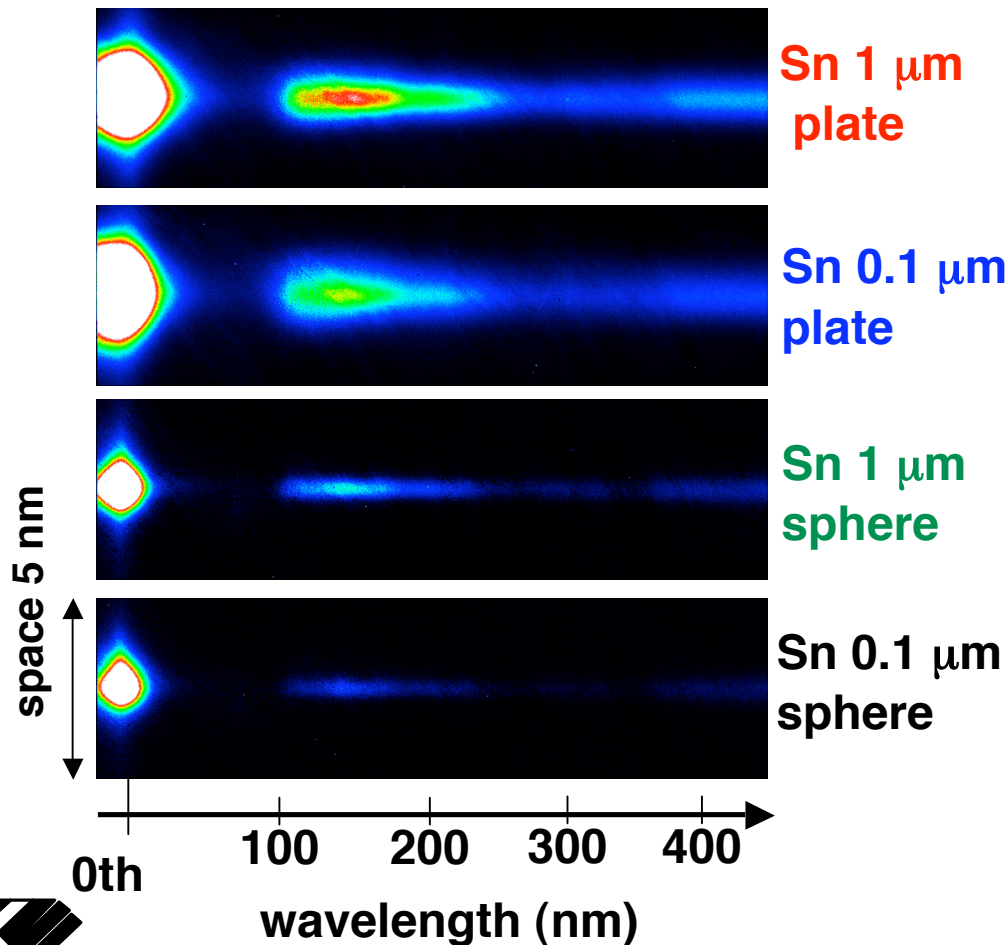
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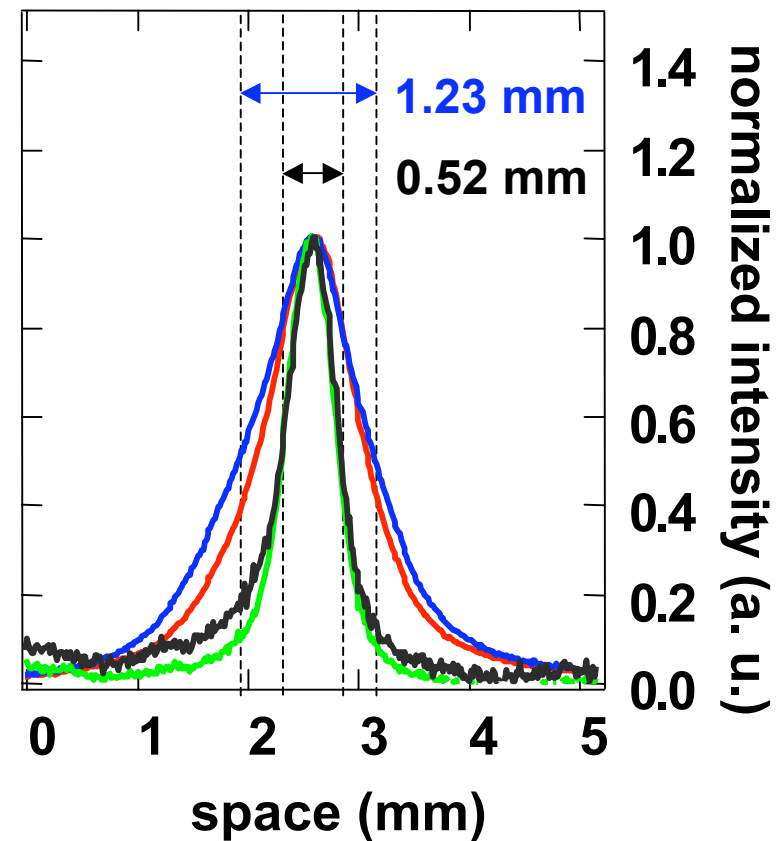


Size of OoB emission region is much wider for planar targets than those for spherical targets, inferring the source of OoB is in the surroundings of laser-spot.

TG+CCD for 8 ns

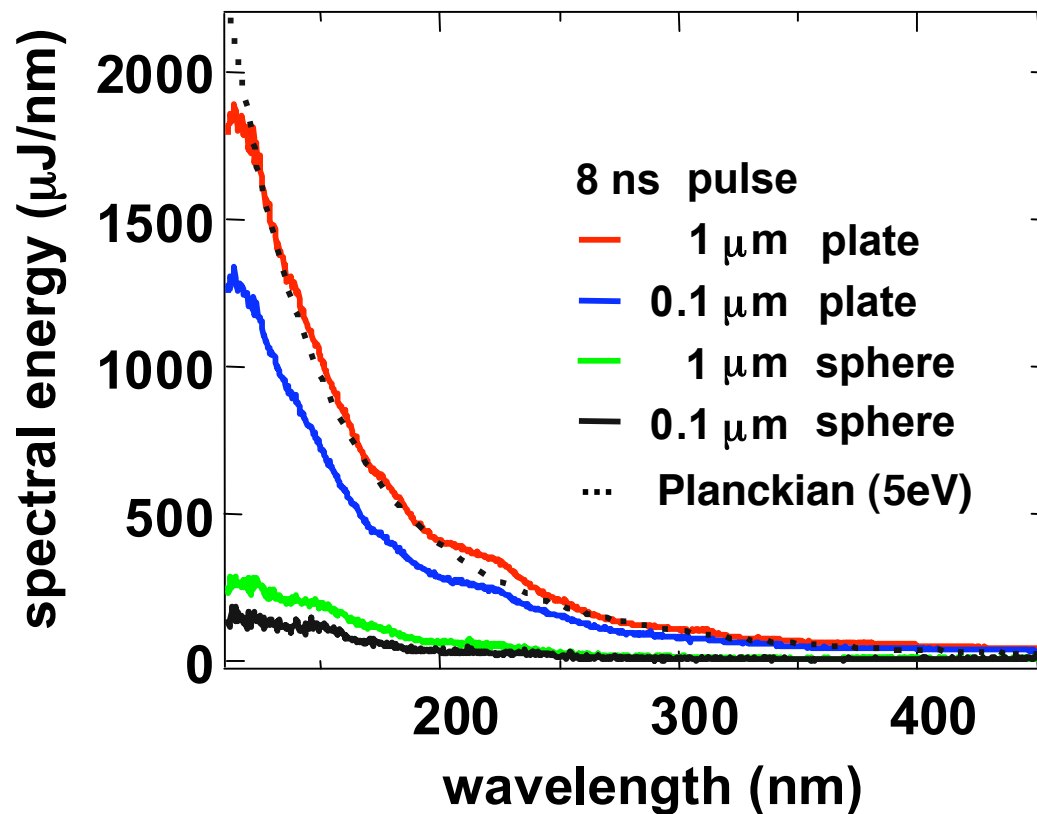


plasma extension  
(integ.: 100–300 nm)



For 8-ns pulse drive, OoB emission energy from spherical targets is 20% or less of those from planar targets

### OoB spectra for 8-ns drive

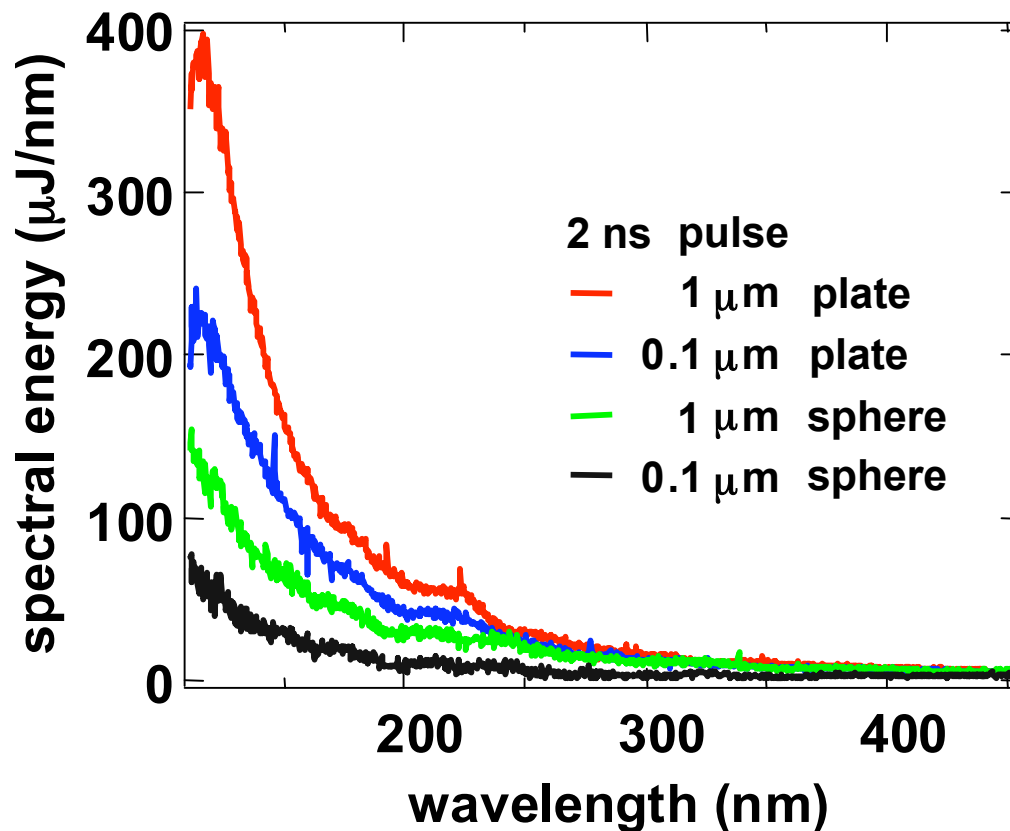


fitting to Planck spectrum  
inferred  $T_R \sim 5 \text{ eV}$

Further reduction of 40% is possible with decrease in the thickness of overcoat from 1 to 0.1  $\mu\text{m}$ .

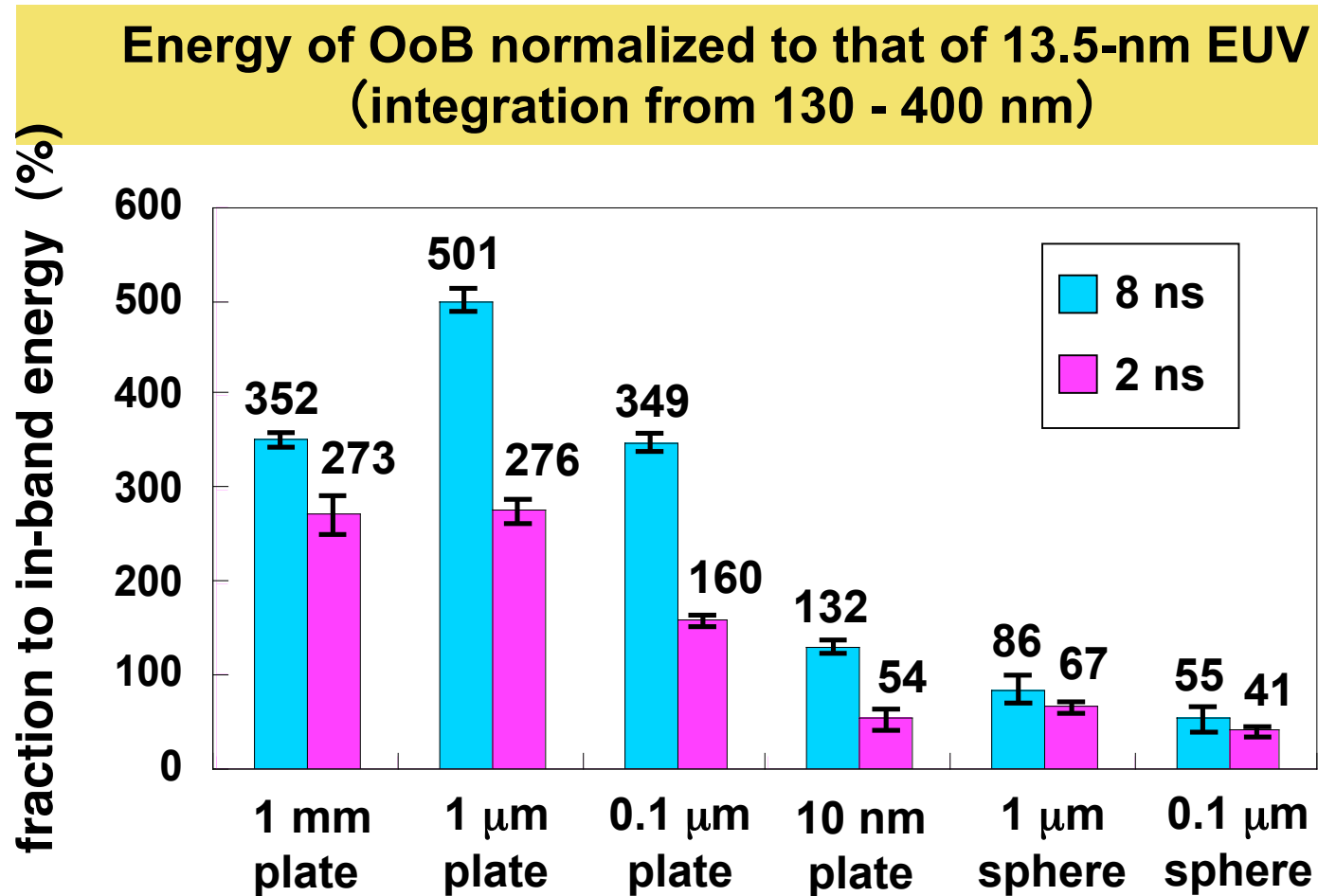
For 2-ns pulse drive, OoB emission energy from spherical targets is less than 25% of those from planar targets

### OoB spectra for 2-ns drive



Further reduction of 50% is possible with decrease in the thickness of overcoat from 1 to 0.1  $\mu\text{m}$ .

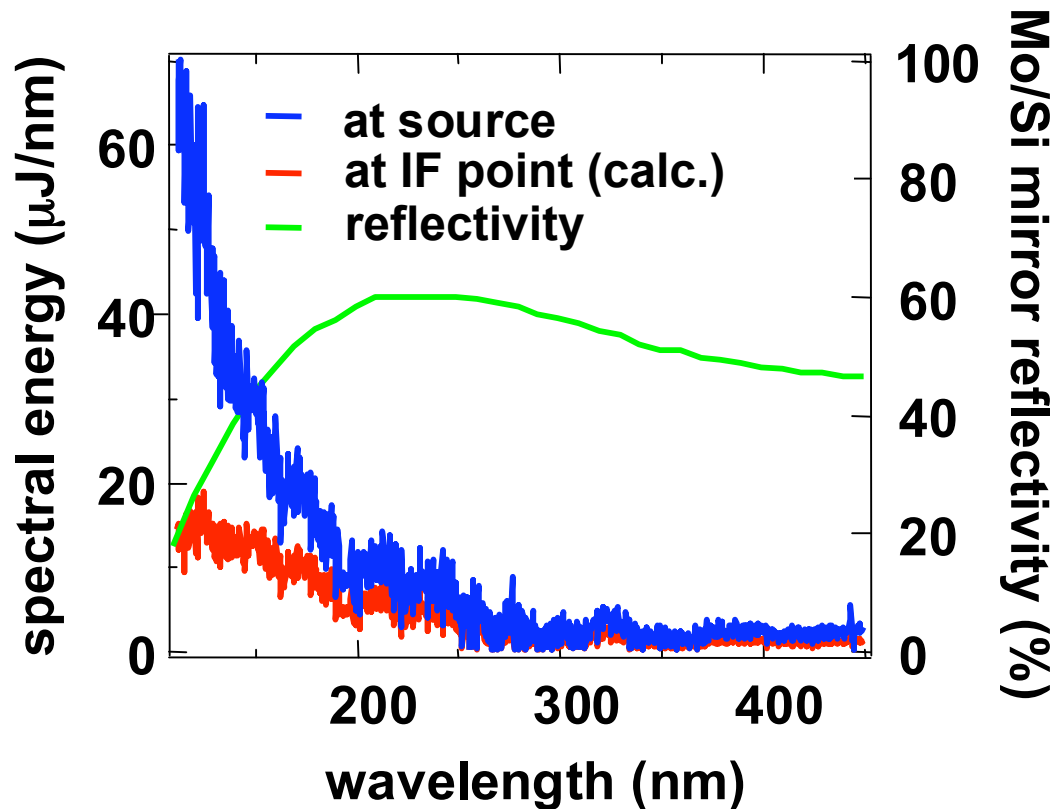
With decrease in Sn thickness and drive-pulse-duration, ratio of energy included in OoB emission to that in the in-band is substantially reduced.



*\*reduction by the first-collection mirror is not included.*

Spectral shape of OoB and reflectivity curve of collection mirror provide effective reflectivity of 31.5% for the 130-400 nm range.

Sn 0.1  $\mu\text{m}$  sphere w/ 2 ns pulse



Energy of OoB emission, in the range of 100 - 400 nm, is 2.78 mJ@source, corresponding to 1.14 mJ@IF or 22.1 % of 13.5-nm EUV. That is about three-times of the joint requirement value of 3-7%

# Summary

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**Out-of-band (OoB) mission spectra in the VUV region (110-400 nm) was absolutely measured for laser produced Sn plasma.**

- 1. With decrease in Sn overcoat thickness and duration of drive laser-pulse, OoB emission substantially decreases whereas conversion to the in-band is kept constant.**
- 2. With decrease in target size down to that of the laser spot, OoB emission decreases, inferring the major source of OoB is in surroundings of the laser spot .**
- 3. Emission energy in the 130-400 nm range at IF point is evaluated to be 22% of 13.5 nm EUV.**

**Use of minimum-mass target enables us to mitigate not only debris but also OoB emission.**